The MJO in Tropical Total Ozone

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Thanks

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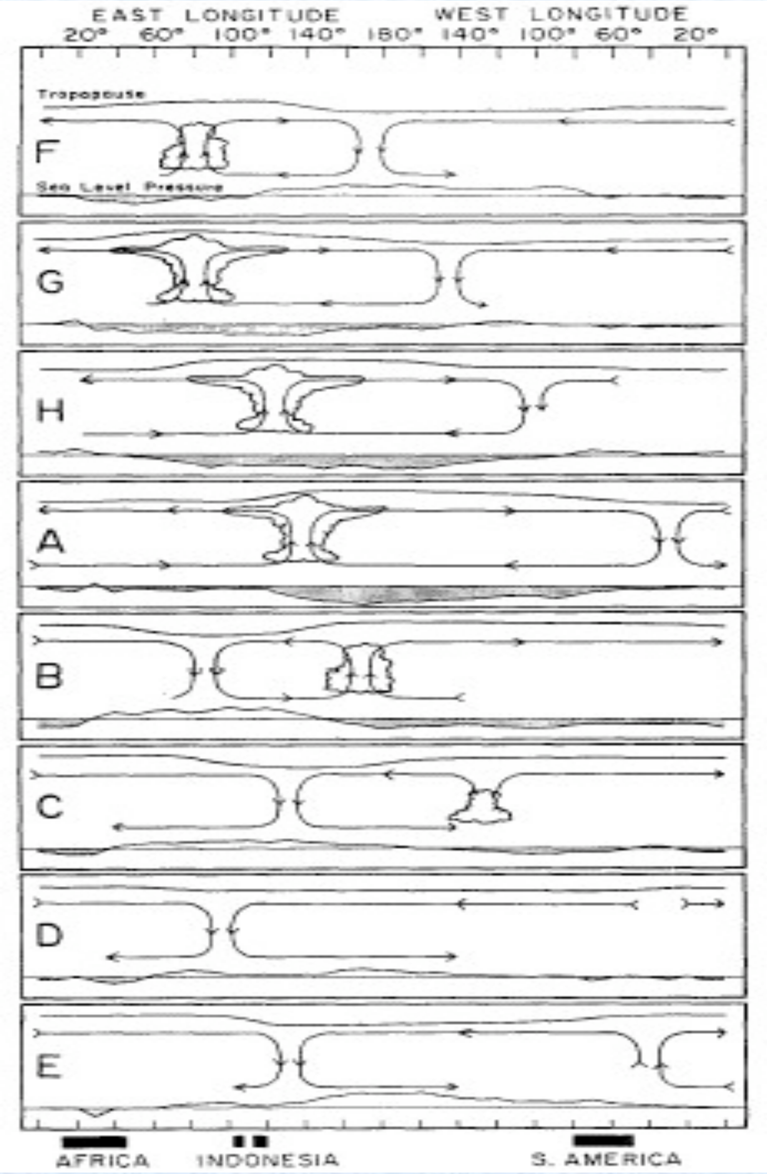
Outline

- ❑ **MJO**
- ❑ **Motivation**
- ❑ **Data and Analysis Methods**
- ❑ **Results and Interpretation**
- ❑ **Summary**

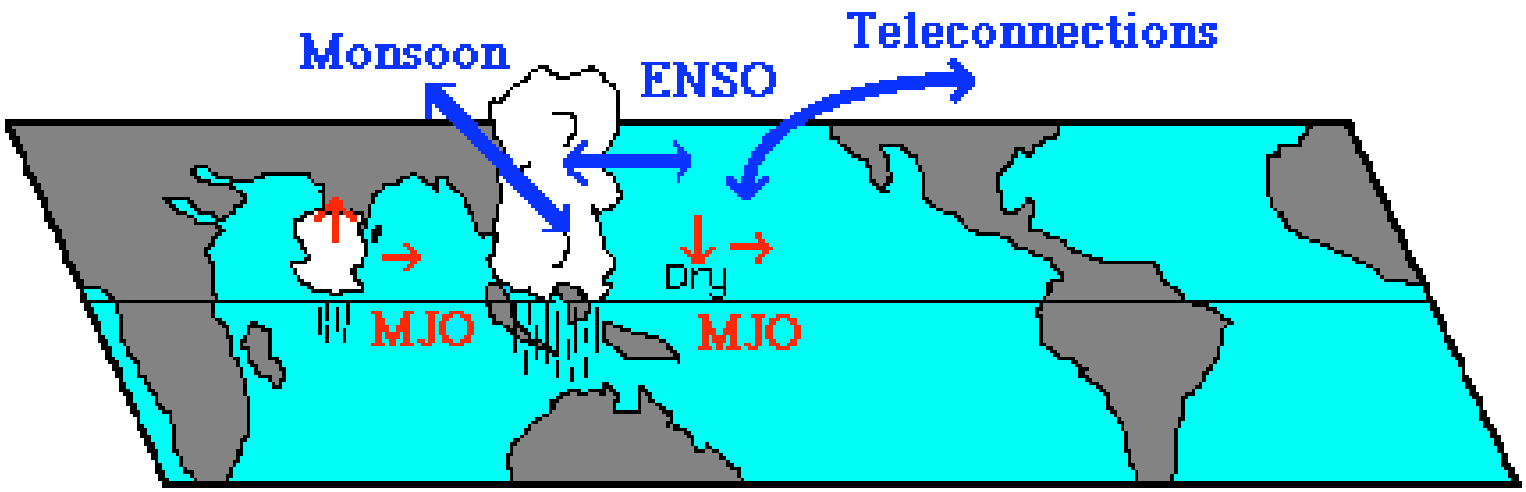
Tian, B., Y. L. Yung, D. E. Waliser, T. Tyranowski, L. Kuai, E. J. Fetzer, and F. W. Irion, 2006: Intraseasonal variations of the tropical total ozone and their connection to the Madden-Julian Oscillation. *Geophys. Res. Lett.*, 10.1029/2007GL029471, in press.

Madden-Julian Oscillation
(a.k.a. Intraseasonal Oscillation)



- ❖ Intraseasonal Time Scale: 30-90 days
- ❖ Slow Eastward Propagation:
  ~5 m/s Phase Speed
- ❖ Strong Coupling Between Deep Convection
  and Large-Scale Circulation
- ❖ Planetary Zonal Scale (Wavenumber One-Two)
- ❖ Vertical Baroclinic Structure
- ❖ Equatorially Trapped
- ❖ Strong Geographic Preference: The Tropical
  Indian and West Pacific Oceans ("Warm Pool")
- ❖Strong Seasonal Dependence:
  NH Winter: Strong; Eastward Propagation
  NH Summer: Weak, Northeast Propagation
- ❖ Significant Interannual Variability
- ❖ Scale Interaction with Many Other High-
  Frequency, Small-Scale Convective Systems

Madden & Julian [1971; 1972], *Lau and Waliser* [2005], *Zhang* [2005]



<Days –Weeks – Months – Seasons -Years->

- ➢ Diurnal Cycle
- ➢ Tropical Weather
  - Low-frequency Weather Modulation
- ➢ Tropical Cyclones and Hurricanes
- ➢ Midlatitude Circulations
- ➢ Asian-Australian Monsoon
  - Onset and Break Periods
- ➢ Tropical Oceans
  - ENSO
  - Decadal Variability (Indian Ocean?)
  - Mean Ocean Climate

Courtesy of D. Waliser

Motivation

However, the impact of the MJO on atmospheric composition, such as ozone, has yet to be well documented.

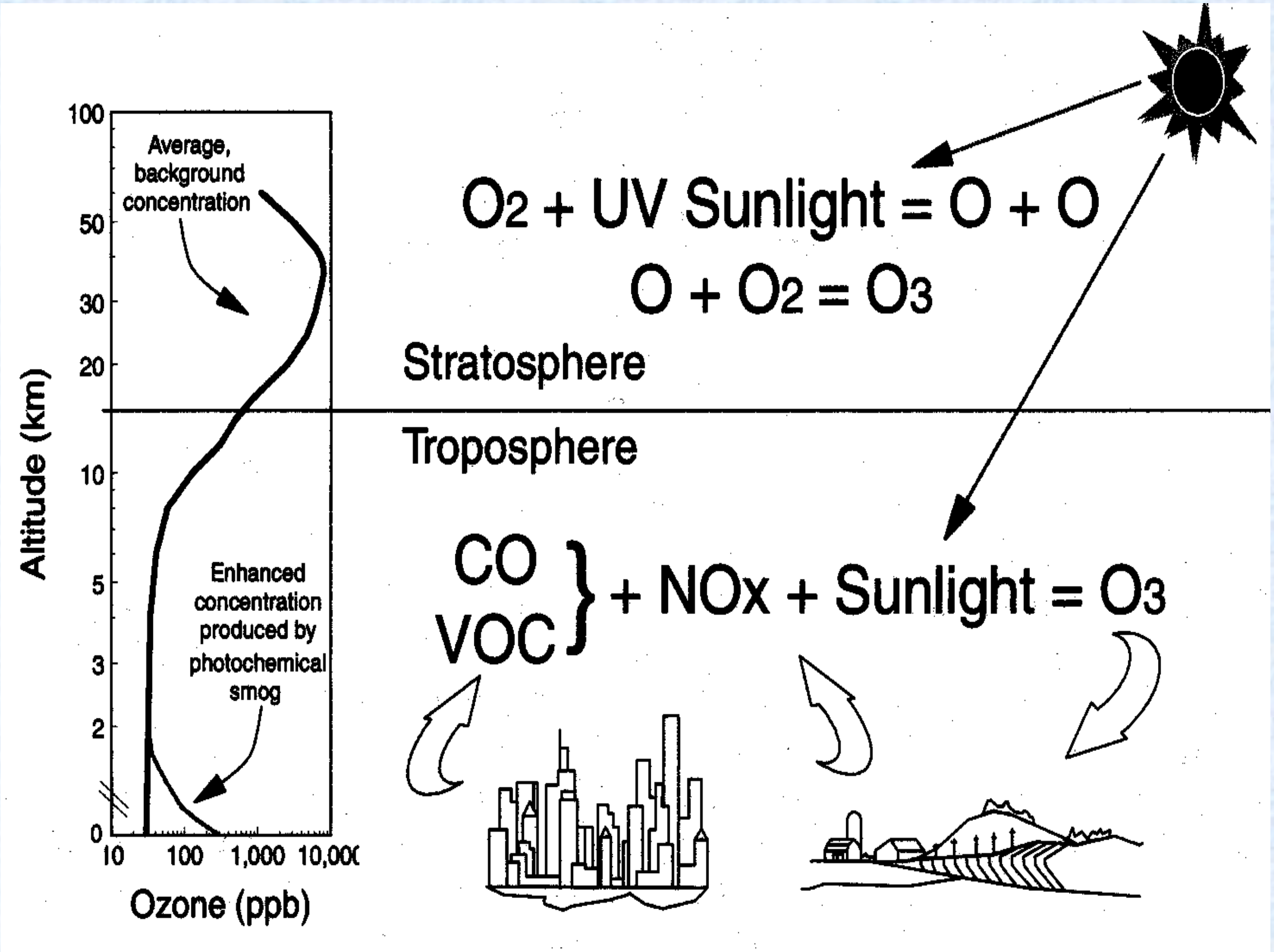
Simplified Chemistry of Ozone

Good
(UV shield)

Bad
(greenhouse gas)

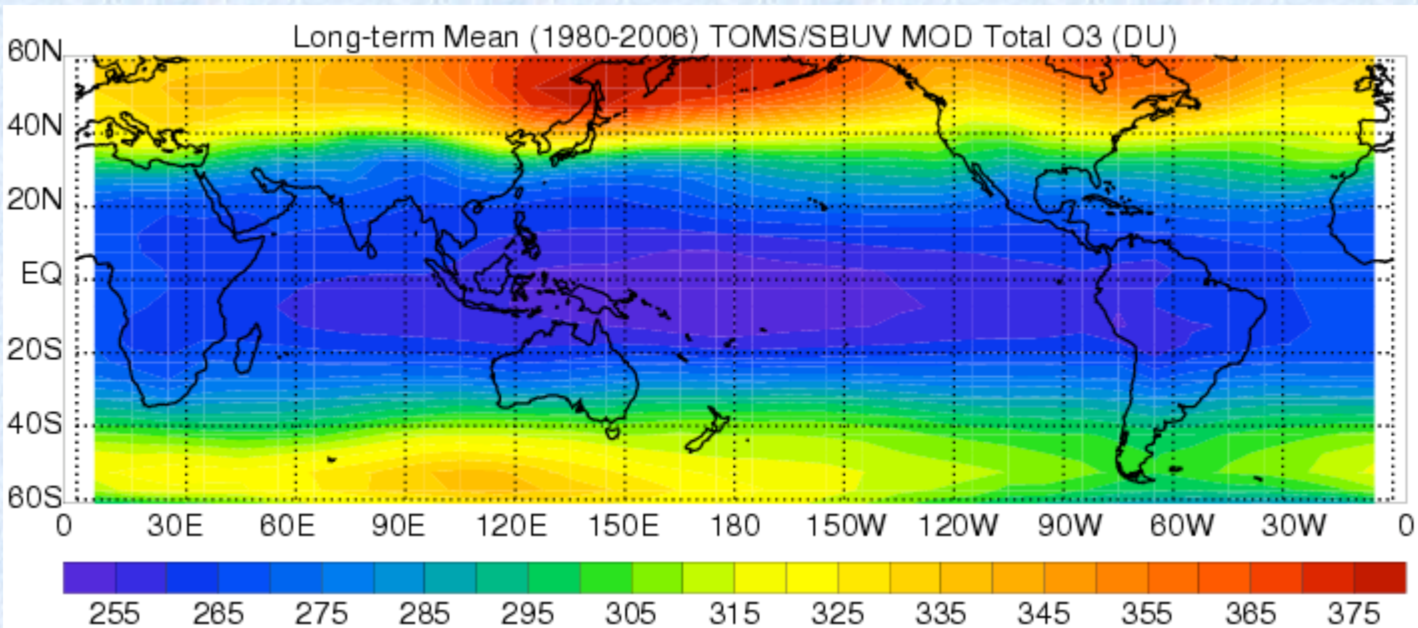
Good
(OH source)

Bad
(smog)



Tropical Total Ozone Variations

Time Scale	Annual Cycle	QBO	ENSO	Solar Cycle	Intraseasonal (MJO)
Magnitude	±10DU (3%)	±15DU (5%)	±10DU (3%)	±5DU (2%)	???



Previous Studies: Limitations

- **Previous studies [e.g., *Sabutis et al.*, 1987; *Gao and Stanford*, 1990; *Fujiwara et al.*, 1998; *Ziemke and Chandra*, 2003; *Londhe et al*., 2005] have investigated the intraseasonal variations of tropical ozone and suggested tacit connections to the MJO.**
- **The spatial and temporal patterns of the intraseasonal variations of tropical total ozone have not been comprehensively documented.**
- **The connection of the ozone intraseasonal variations to the large-scale MJO convection has not been well explained.**

To investigate the spatial and temporal patterns of the intraseasonal variations of tropical total ozone and their connection to the large-scale MJO convection.

Total Ozone Data

➢**Atmospheric Infrared Sounder (AIRS):**

AIRS L3 V4, 1.0° x 1.0°, twice daily, from 09/01/2002 to 07/31/2006

Ref: *Chahine et al.* [2006]

➢**Total Ozone Mapping Spectrometer (TOMS)/Solar Backscatter Ultraviolet (SBUV) Merged Ozone Dataset (MOD) :**

V8, 5°x10° lat-long, daily, from 01/01/1980 to 06/30/2006

6 satellite instruments:

Nimbus-7 and Earth Probe TOMS,

Nimbus-7 SBUV,

NOAA 9, 11, and 16 SBUV2s

Ref: *Stolarski and Frith* [2006]

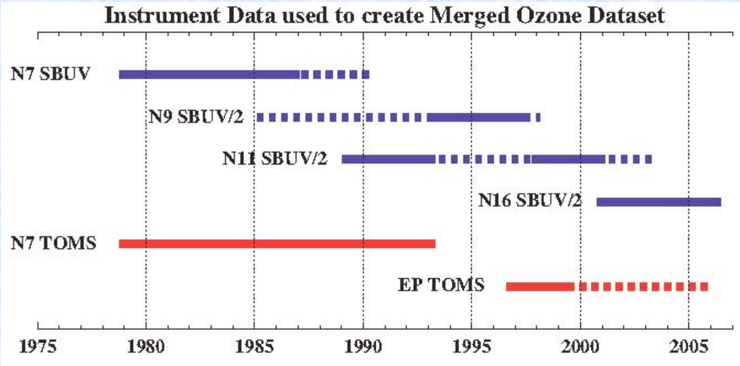


Fig. 1. Instruments used to create merged ozone data set. Solid lines indicate time when data was used. Dashed lines indicate time when data was available, but not used for reasons explained in the text.

Other Data

- **CMAP Rainfall:**

  2.5° x 2.5°, pentad, from 01/01/1979 to 05/31/2006

- **NCEP/NCAR Reanalysis Dynamical Fields:**

  Daily Geopotential Height and Stream Function (calculated based on horizontal winds)

  2.5° x 2.0°, from 01/01/1979 to 12/31/2006

MJO Analysis and Event Selection

(1) **Binning the data into 5-day average (pentad) values.**

(2) **Removing the annual cycle.**

(3) **Band-pass filtering (30-90 day) the data.**

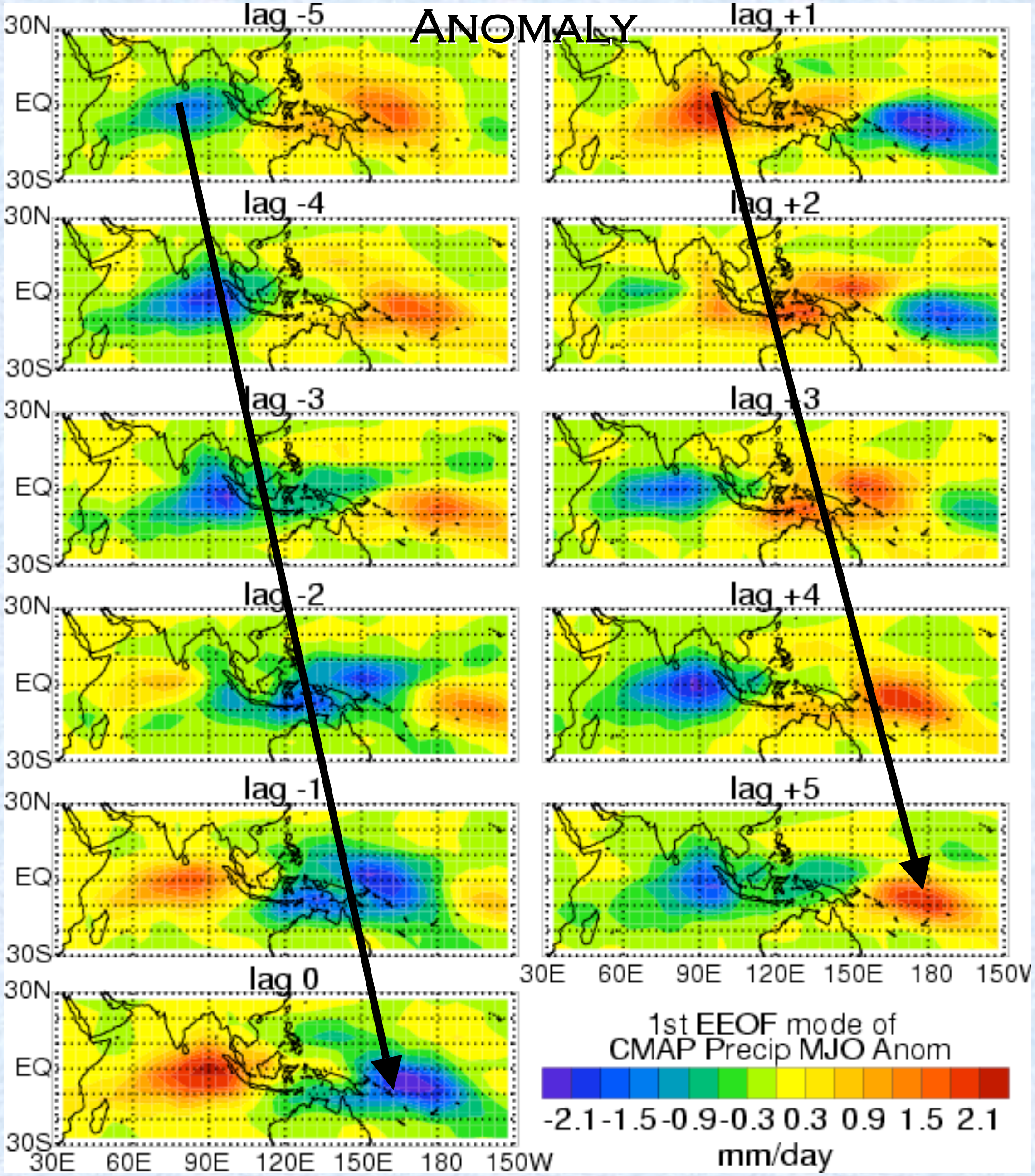
(4) **Identifying MJO events using Extended EOF analysis using +/- 5 pentad lags (= 11 pentads = 55 days) of rainfall anomaly.**

(5) **Composite selected MJO events.**

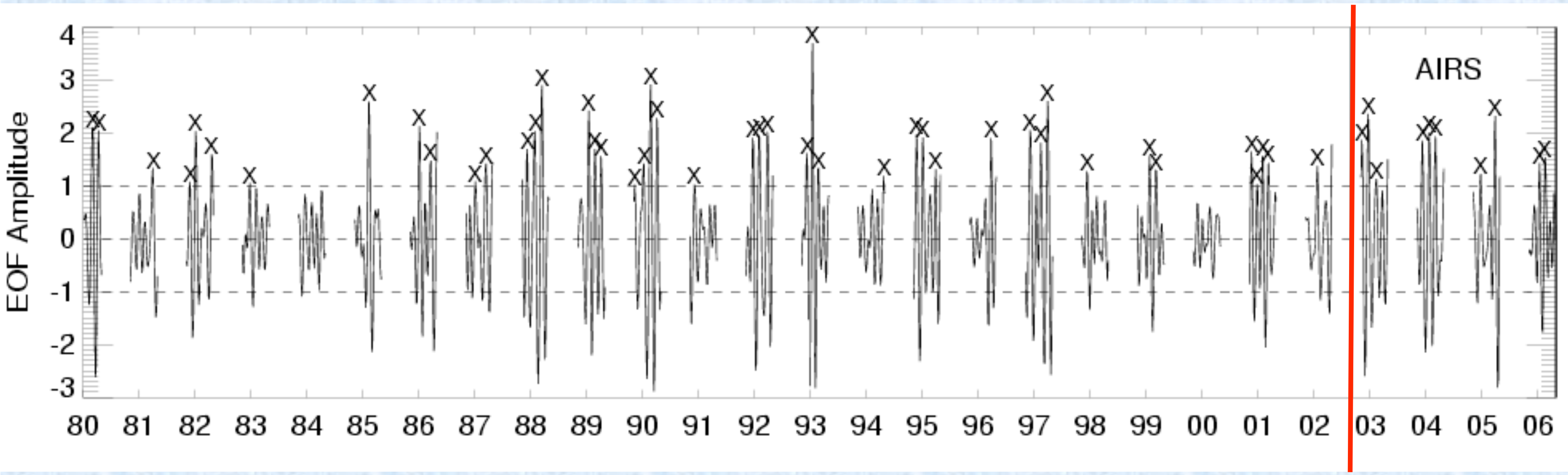
Methodology References:

Tian, B., D. E. Waliser, E. J. Fetzer, B. Lambrigtsen, Y. L. Yung, and B. Wang, 2006: Vertical moist thermodynamic structure and spatial-temporal evolution of the MJO in AIRS observations. *J. Atmos. Sci.*, **63**, 2462-2485.

Spatial-temporal Pattern of the 1st EEOF Mode of Rainfall MJO Anomaly



Amplitude Time Series of the 1st EEOF Mode of Rainfall MJO Anomaly



55 and 10 MJO events were selected for MOD and AIRS

Total Ozone MJO Anomaly from AIRS

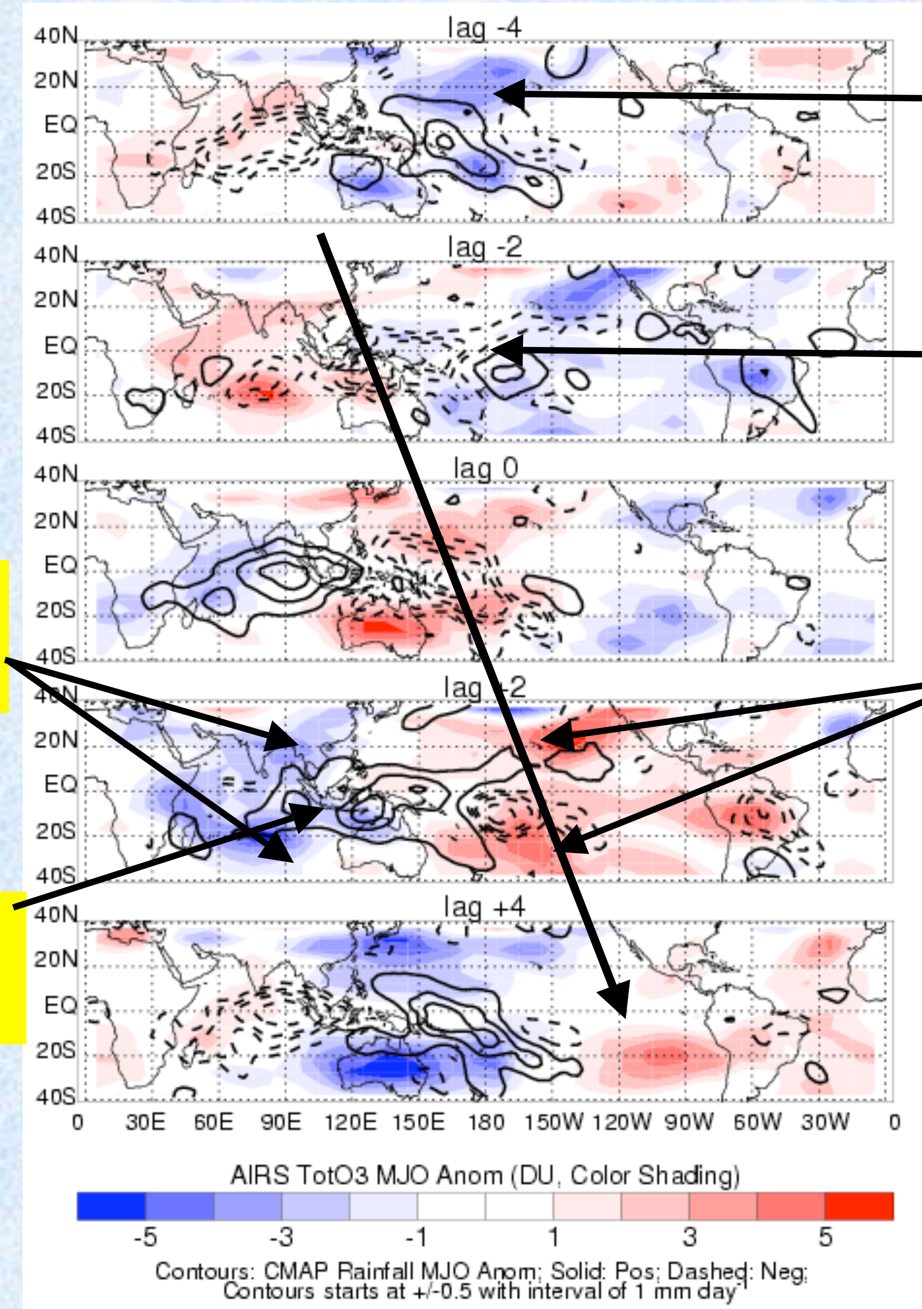
Subtropical O3 anomalies are large

Equatorial O3 anomalies are small

Subtropical negative O3 anomalies lag EQ MJO convection

Subtropical positive O3 anomalies lead EQ MJO convection

Equatorial enhanced MJO convection (positive, solid, rainfall anomaly)

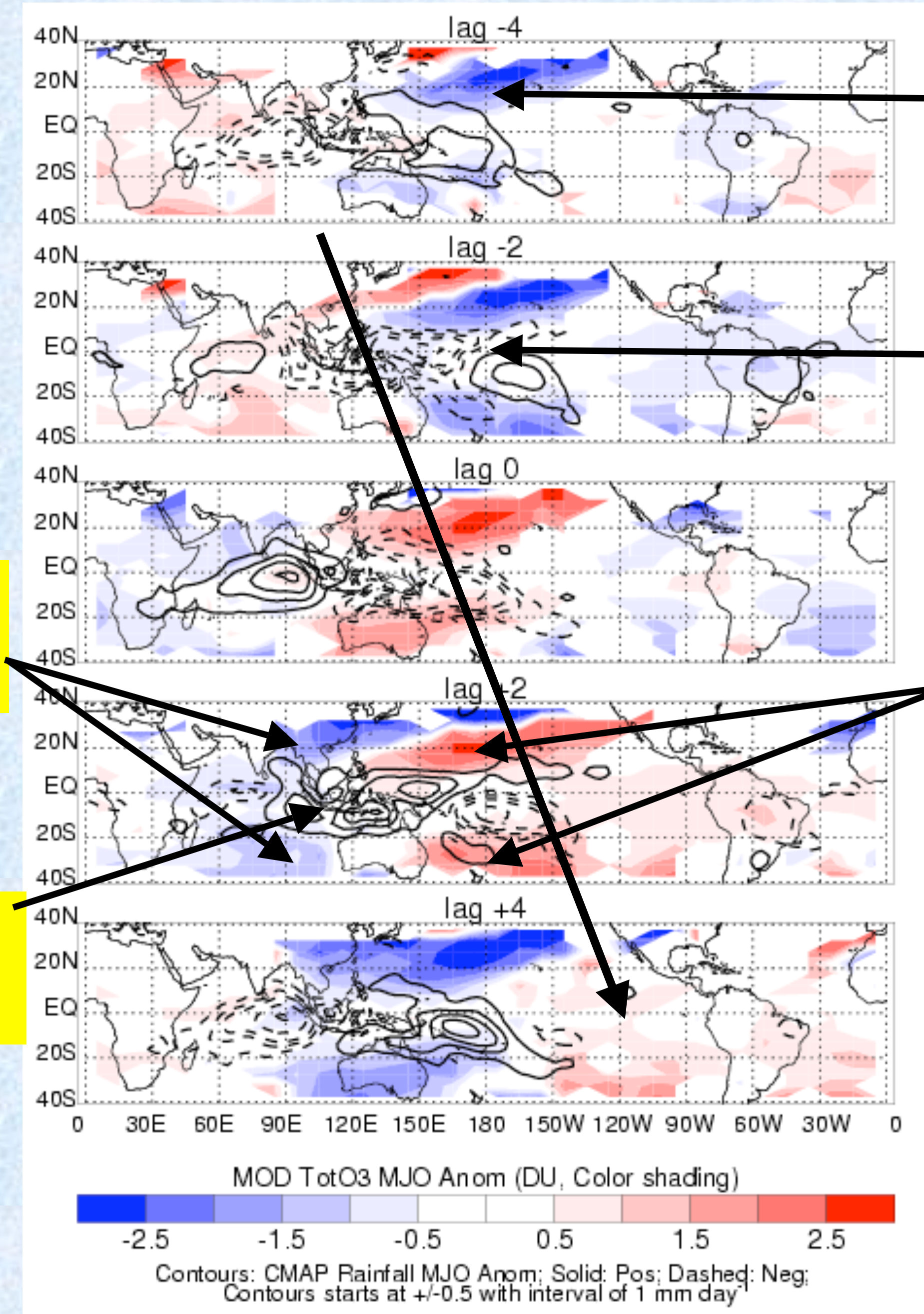


0

+10 Days

+20 Days

Total Ozone MJO Anomaly from MOD



Subtropical O3 anomalies are large

Equatorial O3 anomalies are small

Subtropical negative O3 anomalies lag EQ MJO convection

0 Days

Subtropical positive O3 anomalies lead EQ MJO convection

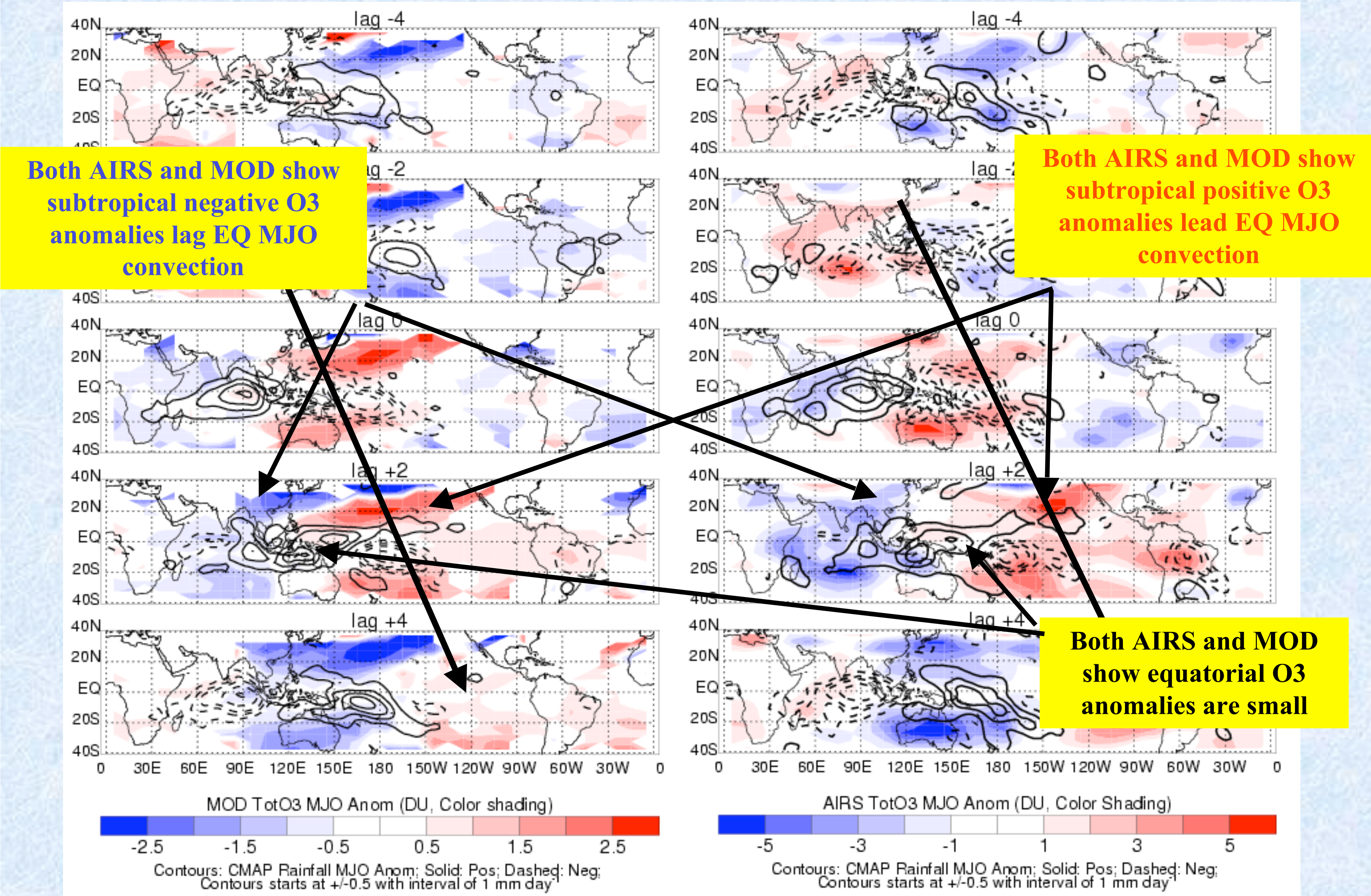
+10 Days

Equatorial enhanced MJO convection (positive, solid, rainfall anomaly)

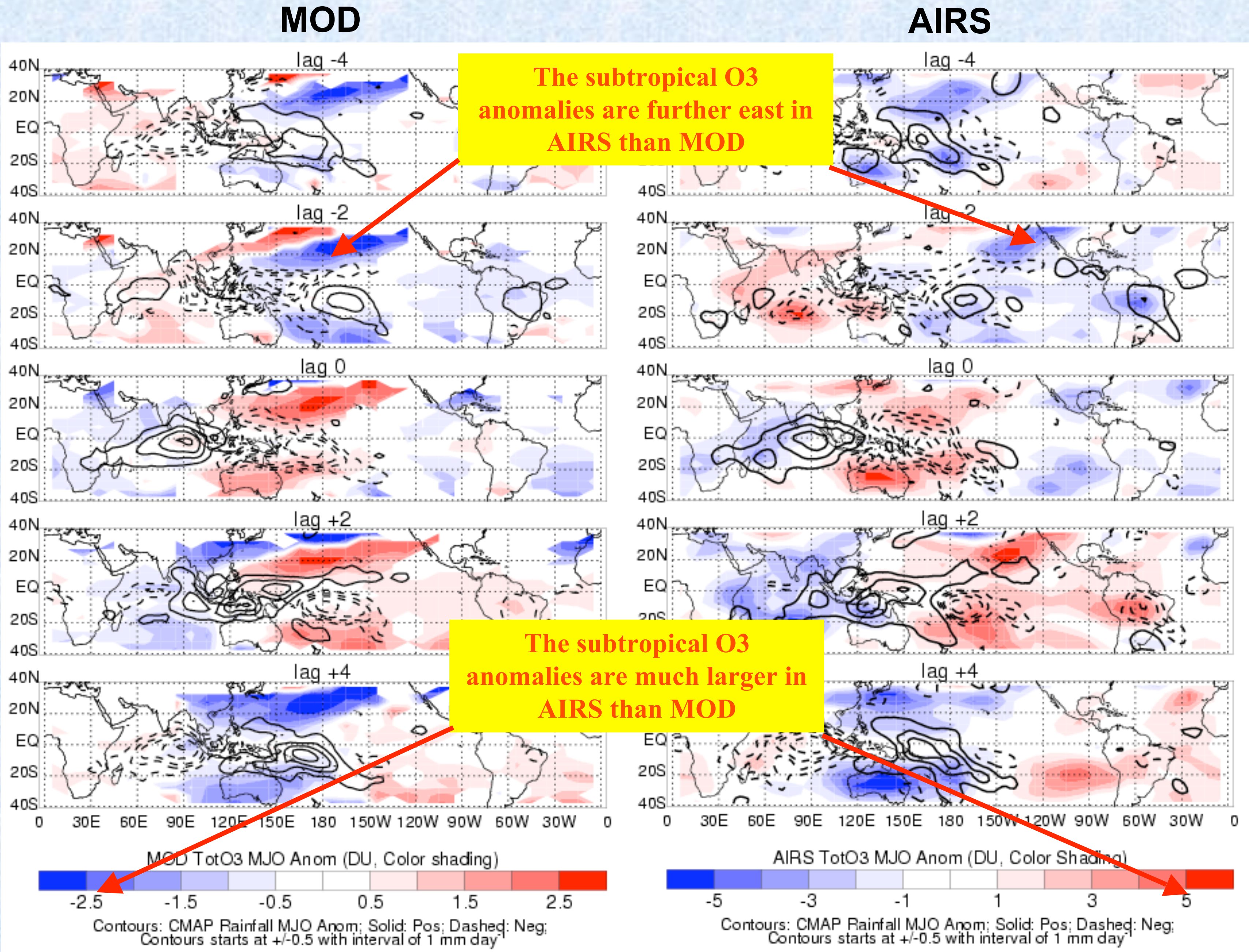
+20 Days

Total Ozone MJO Anomaly--Similarity

MOD **AIRS**

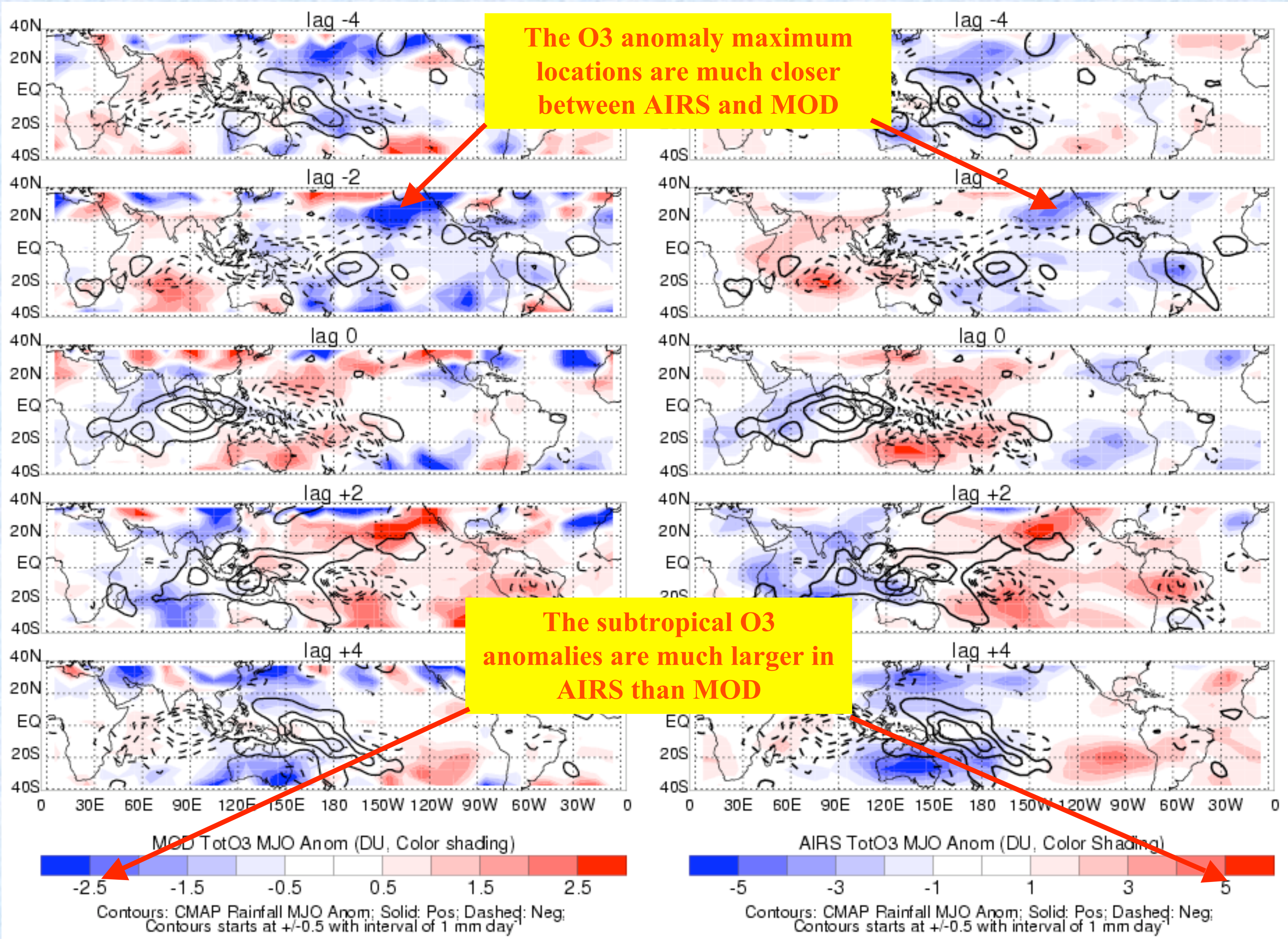


Total Ozone MJO Anomaly--Differences



Total Ozone MJO Anomaly--Differences

MOD **AIRS**



Dynamic Connection btw the Subtropical Ozone Anomalies and the Equatorial MJO Convection

- **First, it is well known that the total ozone variations are closely connected to the vertical movement of the tropopause at daily and synoptic time scales [e.g., *Reed*, 1950; *Schubert and Munteanu*, 1988; *Mote et al.*, 1991; *Salby and Callaghan*, 1993; *Steinbrecht et al.*, 1998].** **→intraseasonal time scale?**

- **Second, the equatorial MJO convection can generate upper-troposphere cyclones or anticyclones over the subtropics [e.g., *Rui and Wang*, 1990; *Hendon and Salby*, 1994; *Highwood and Hoskins*, 1998; *Matthews et al.*, 2004].** **→ influencing the subtropical tropopause?**

Connection btw Total O3 and TTL GPH Anomalies

-20 Days

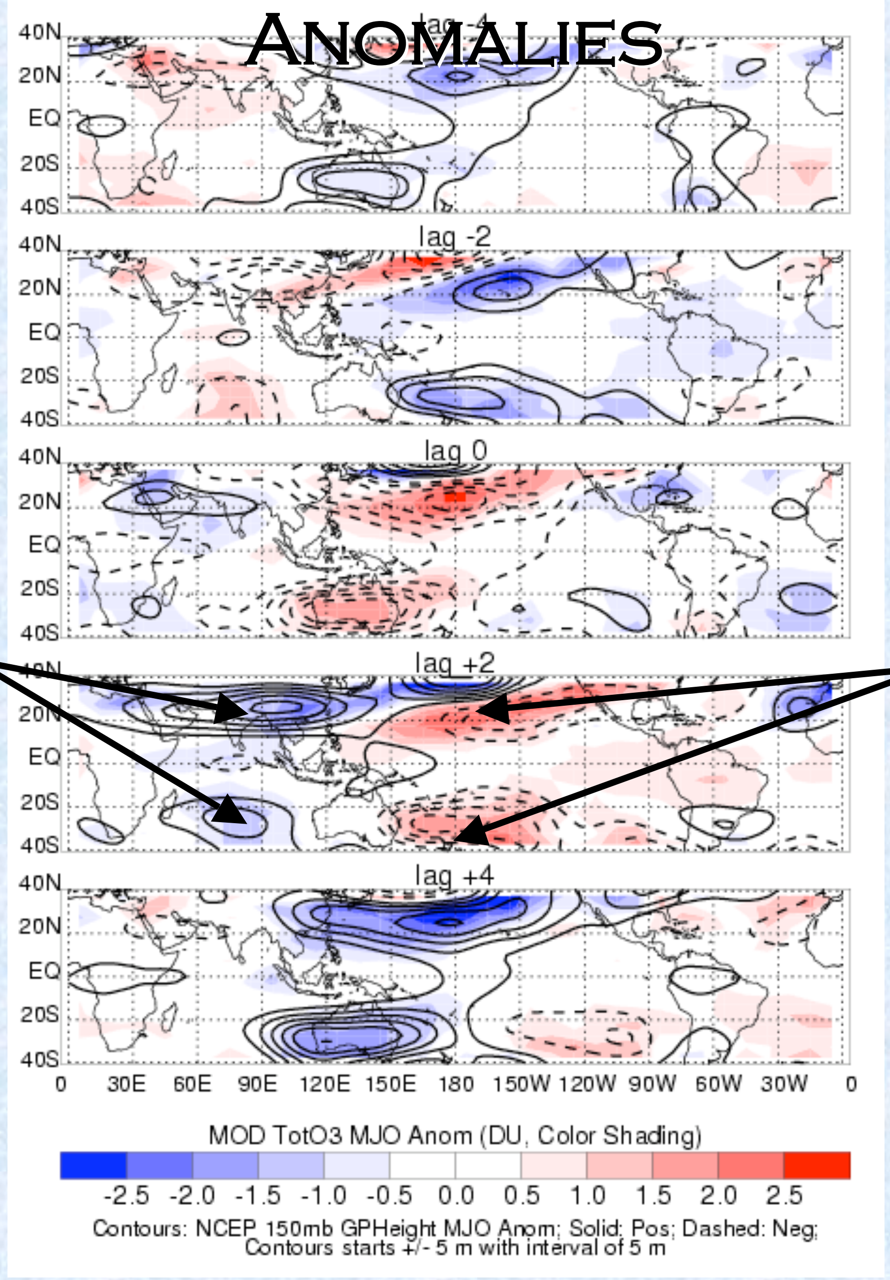
Tropopause moves up

Tropopause moves down

0 Days

Subtropical negative total O3 anomalies are coincident with the subtropical positive 150mb geopotential height anomalies.

Subtropical positive total O3 anomalies are coincident with the subtropical negative 150mb geopotential height anomalies.



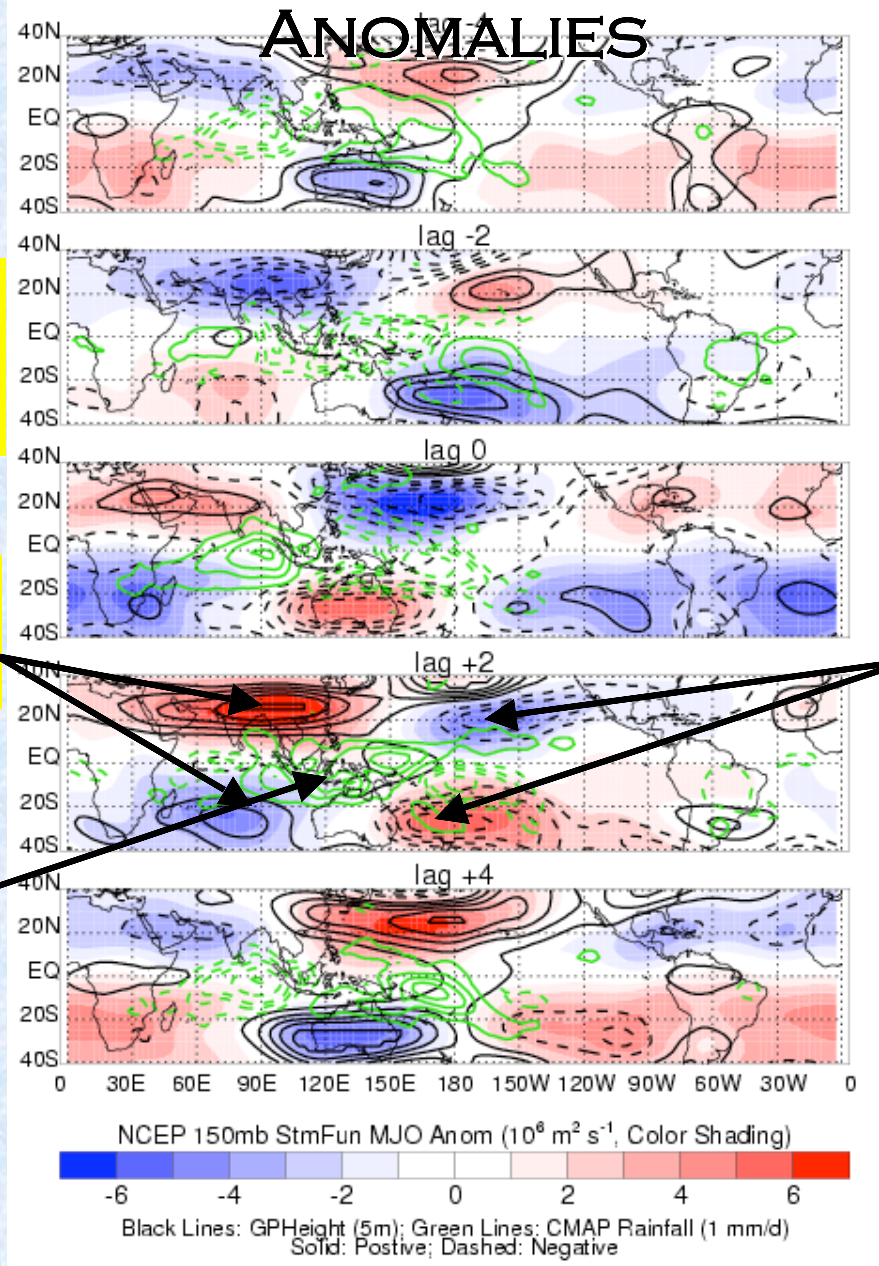
+20 Days

Connection btw TTL GPH, StmFun and Prec Anomalies

Upward movement of subtropical tropopause (positive GPH) is the result of the UT anticyclones

Two UT anticyclones in the subtropics lag the equatorial MJO convection

Equatorial enhanced MJO convection (positive rainfall anomaly)



-20 Days

Downward movement of subtropical tropopause (negative GPH) is the result of the UT cyclones

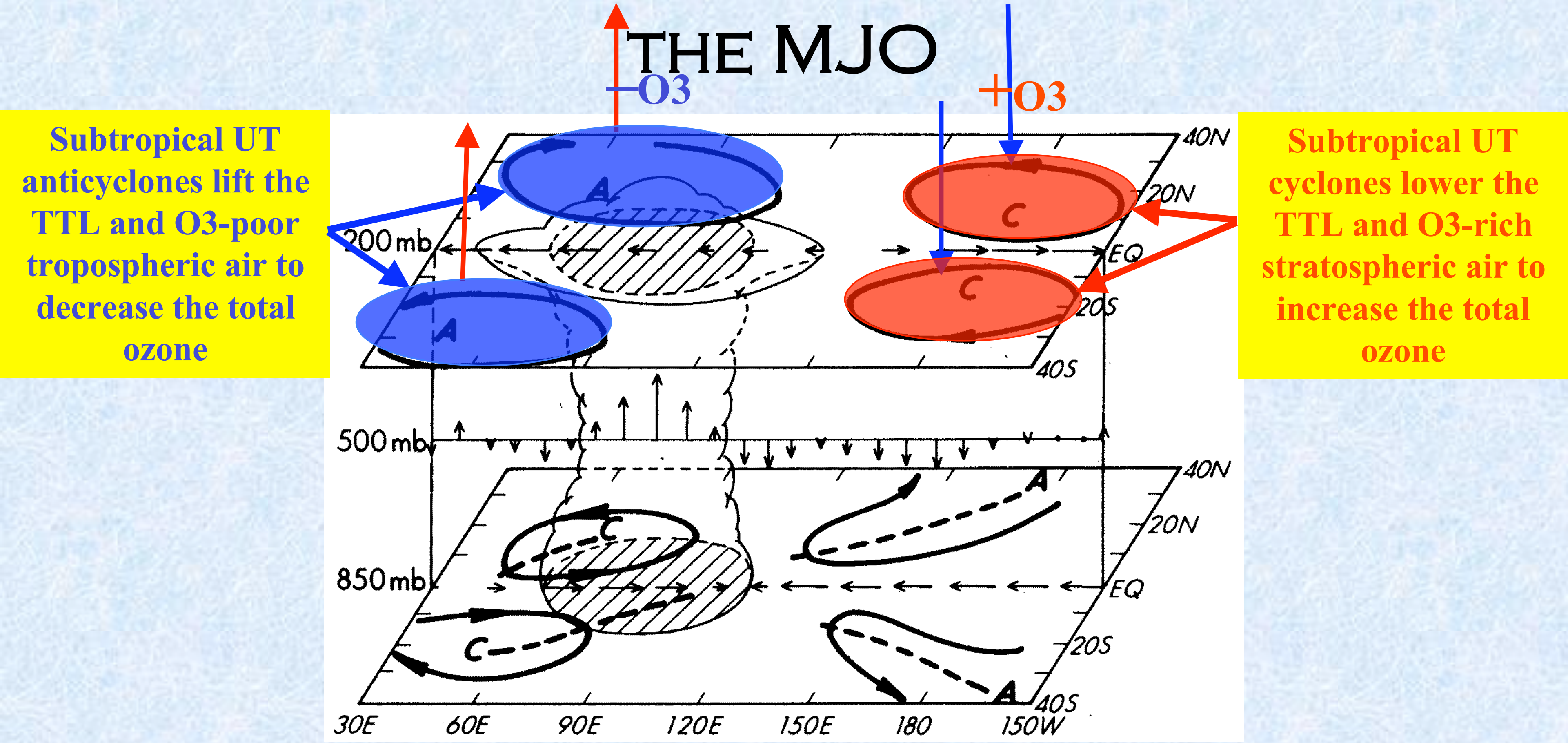
0 Days

Two UT cyclones in the subtropics lead the equatorial MJO convection

+10 Days

+20 Days

Schematic of the Total Ozone Anomalies and Their Connection to the MJO



The cloud symbol indicates the convective center. Arrows represent anomalous winds at 850 and 200 hPa and the vertical motions at 500 hPa. ''A'' and ''C'' mark the anticyclonic and cyclonic circulation centers, respectively. Dashed lines mark troughs and ridges. From *Rui and Wang* [1990].

Summary

➢Based on AIRS and TOMS/SBUV data, we found that the intraseasonal variations of tropical total ozone are large (~±10DU).

➢Intraseasonal total ozone anomalies are mainly evident in the subtropics, while equatorial ozone anomalies are small. The subtropical positive (negative) ozone anomalies flank or lie to the west of equatorial suppressed (enhanced) MJO convection anomaly and propagate slowly eastward (~5m/s).

➢The subtropical ozone anomalies are caused by the vertical movement of the subtropical tropopause and thus are mainly associated with ozone variability in the stratosphere rather the troposphere. The vertical movement of the subtropical tropopause is driven by the upper-troposphere cyclones (anticyclones) in the subtropics that are generated by equatorial MJO convection.

➢This study demonstrates the potential of the AIRS ozone to improve our understanding of ozone chemistry and its effects on climate change.

Possible Reasons for the Differences

- **First, MOD and AIRS use different retrieval techniques (UV backscatter for MOD and infrared emission for AIRS) and thus have different sampling characteristics (daytime for MOD and both day and night for AIRS).**

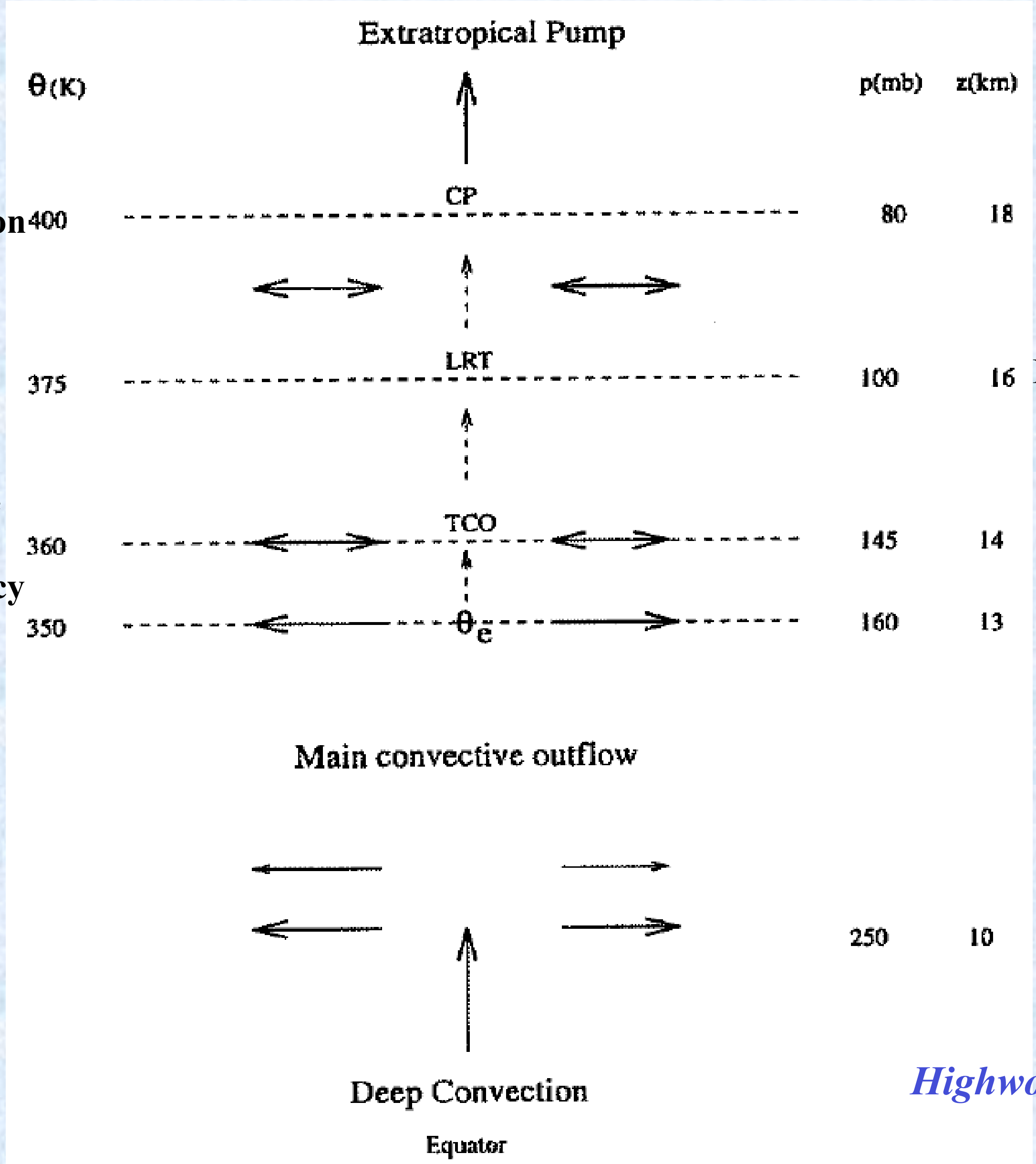
- **Second, both MOD and AIRS may have retrieval biases, especially over the equatorial regions where optically thick clouds are abundant associated with equatorial deep convection.**

- **Third, AIRS seems to have more sensitivity than MOD.**

Tropical Tropopause Layer (TTL)

Highest Level of Overshooting Convection

Level of Zero Radiative Heating or Maximum Level of Neutral Buoyancy



Cold Point Tropopause

Lapse Rate Tropopause

Top of Convective Overflow

Highwood and Hoskins [1998]

Tropical Tropopause Layer (TTL)

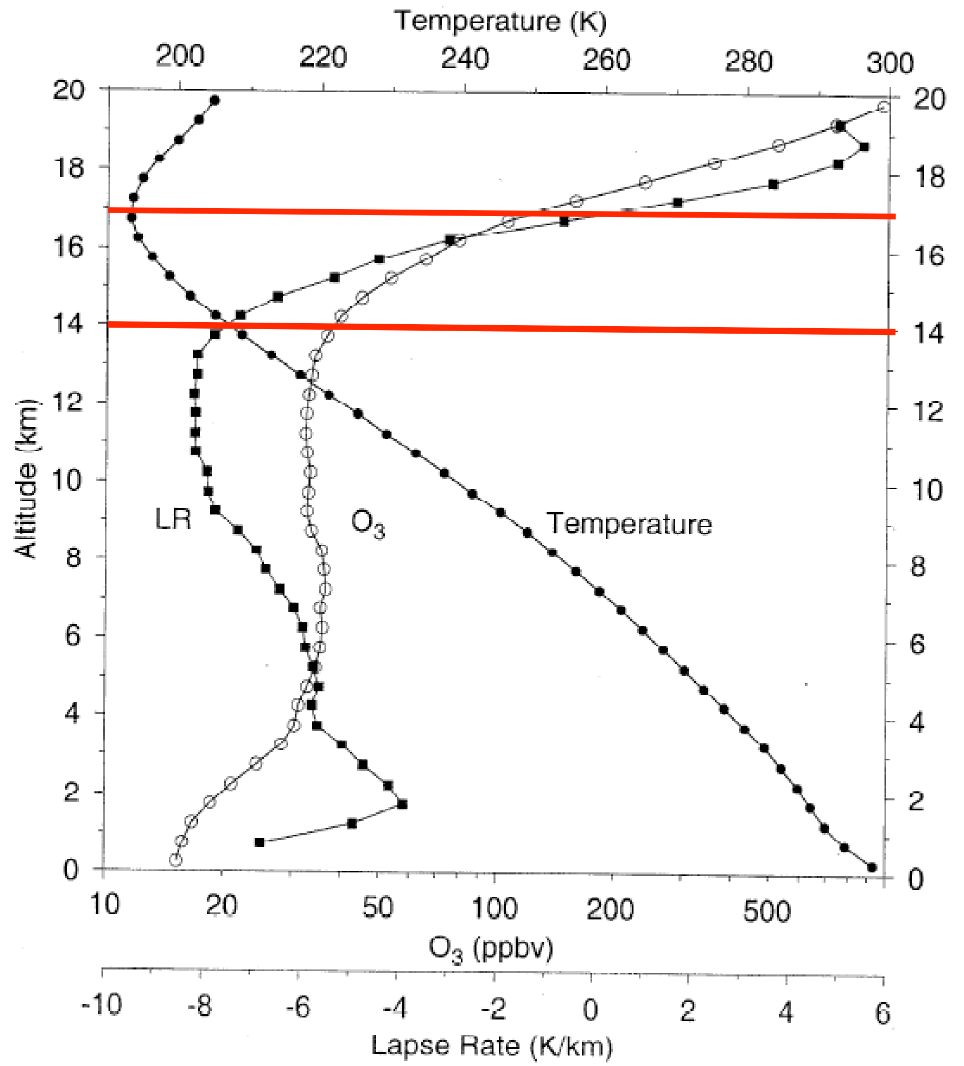


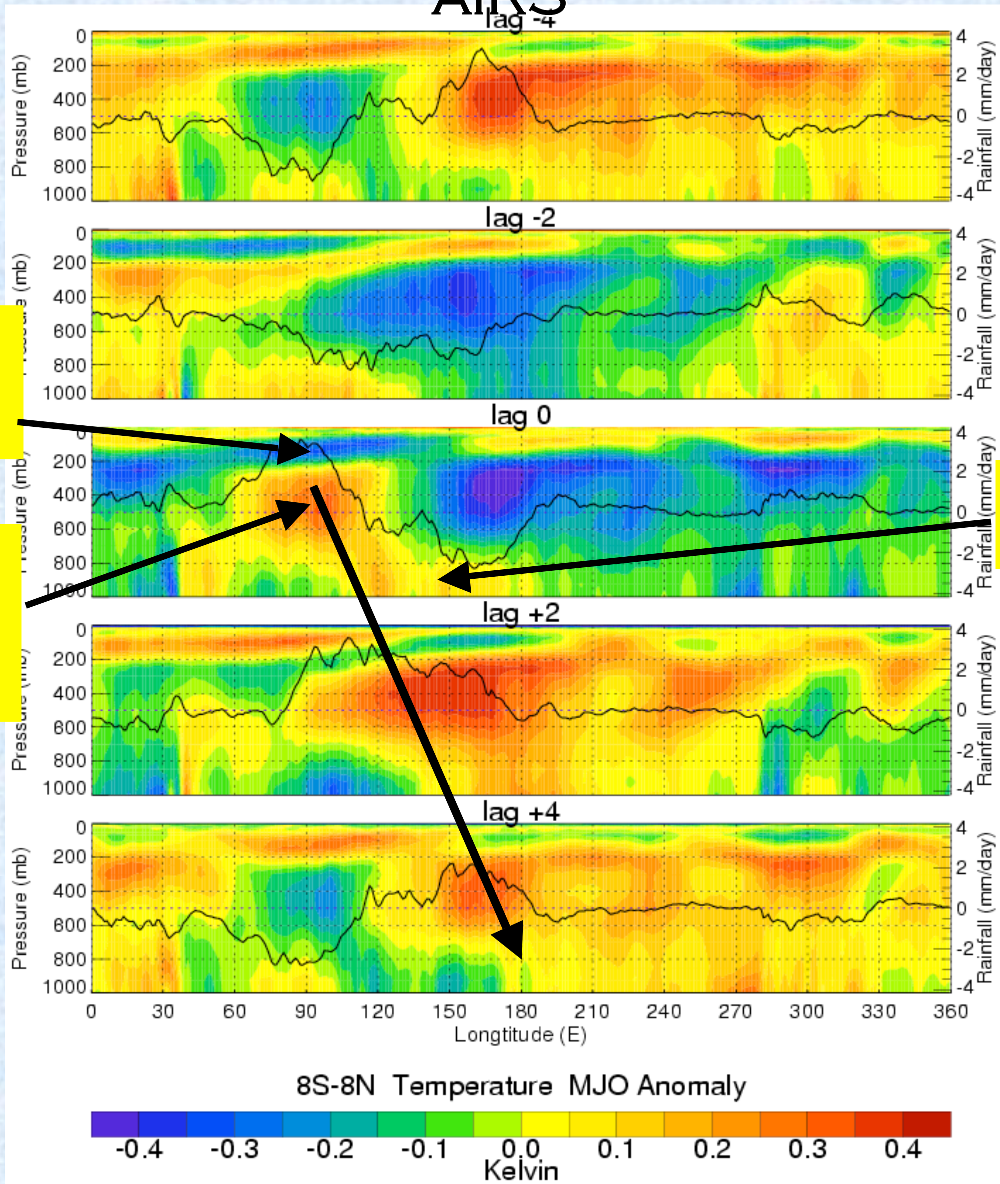
Figure 2. Average profiles of temperature, O_3, and lapse rate(LR) from all 108 Samoan ozonesondes.

Cold Point Tropopause

Top of Convective Overflow (TCO)-- Chemopause

***Folkins et al.* [1999]**

Pres-Long Diagrams of MJO Temp Anomaly Along Equator from AIRS



-20 Days

-10 Days

+10 Days

+20 Days

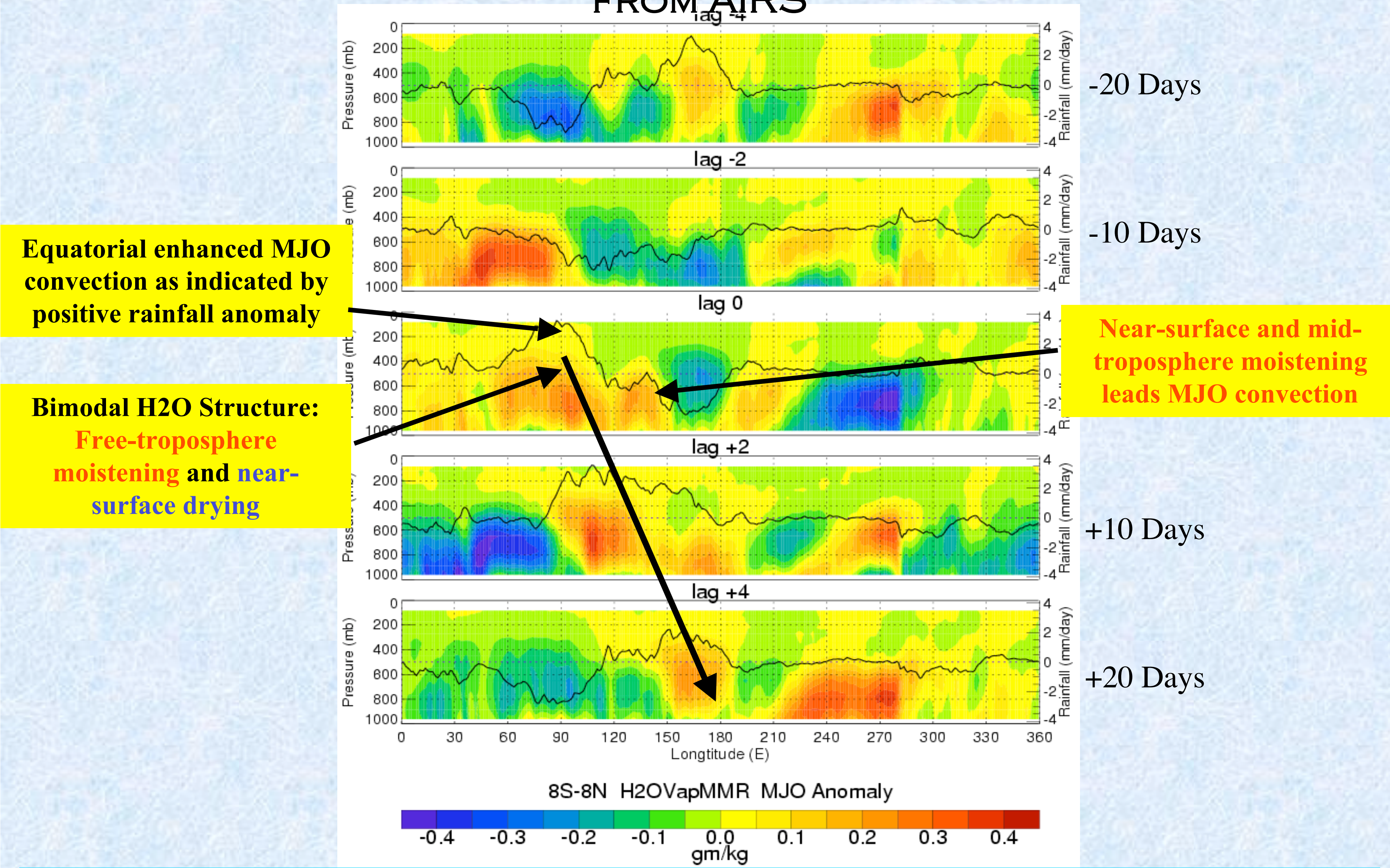
Equatorial enhanced MJO convection as indicated by positive rainfall anomaly

Trimodal Temp Structure: Free-troposphere warming and boundary-layer and tropopause- layer cooling

Boundary-layer warming leads MJO convection

Tian, B., Waliser, Fetzer, Lambrigtsen, Yung, and Wang, 2006: Vertical moist thermodynamic structure and spatial-temporal evolution of the MJO in AIRS observations. *J. Atmos. Sci.*, **63**, 2462-2485.

Pres-Long Diagrams of MJO Moisture Anomaly along Equator from AIRS



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